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NAVAL AIR WARFARE CENTER AIRCRAFT DIVISION
PATUXENT RIVER, MARYLAND

TECHNICAL REPORT

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SEA LEVEL OPERATION DEMONSTRATION OF F404-GE-400 TURBOFAN ENGINE WITH JP-5/BIO-FUEL MIXTURE

by

Christopher Chippa

30 March 2010

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DEPARTMENT OF THE NAVY
NAVAL AIR WARFARE CENTER AIRCRAFT DIVISION
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SUMMARY

An engine performance test was conducted on an uninstalled F404-GE-400 turbofan engine inside the Aircraft Test and Evaluation Facility Hush House at Naval Air Station Patuxent River, Maryland, on 13 October 2009. The test consisted of two separate engine performance demonstration runs through the full power range of operation using JP-5 fuel and a blend of JP-5 and a plant-based Bio-fuel. Specifically, the Bio-fuel was derived from the flowering plant known as camelina sativa and was manufactured by Sustainable Oils of Bozeman, Montana. The blended fuel consisted of 45% Bio-fuel and 55% JP-5 by volume. Analysis of the corrected performance data revealed no significant change in engine performance or operation.

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INTRODUCTION

BACKGROUND

1. An engine performance test was conducted on an uninstalled F404-GE-400 turbofan engine (ESN 310810) inside the Aircraft Test and Evaluation Facility Hush House at Naval Air Station (NAS) Patuxent River, Maryland, on 13 October 2009. The test consisted of two separate engine performance demonstration runs through the full power range of operation using JP-5 fuel and a blend of JP-5 and a plant-based Bio-fuel. Specifically, the Bio-fuel was derived from the flowering plant known as camelina sativa and was manufactured by Sustainable Oils of Bozeman, Montana. The blended fuel consisted of 45% Bio-fuel and 55% JP-5 by volume.

TEST EXECUTION

2. The engine run profile used for each of the two fuels tested consisted of the same target fan speeds, sequence, and stabilization times. The engine run profile used for this test closely matched the profile of the standard F404 engine performance verification testing. Stabilization times for performance test points below Intermediate Rated Power (IRP) were decreased from 5 min to 4 min to conserve the limited Bio-fuel.

3. The test was initiated with the engine operating using JP-5 fuel and was subjected to the full range of power settings. While operating at the ground idle power setting, the engine fuel supply was switched to the JP-5/Bio-fuel blend and the engine was subjected to the full range of power settings. Steady state performance data were collected at each test point throughout the two engine runs. Engine test points are illustrated in table 1.

Table 1: Engine Test Points

Test Point	Engine Setting	Duration (min)
Start Engine using JP-5		
1	Ground Idle	5
2	IRP	5
3	Max A/B	1
4	IRP-200 N1	4
5	IRP-400 N1	4
6	IRP-600 N1	4
7	IRP-800 N1	4
8	IRP-1000 N1	4
9	IRP-1200 N1	4
10	IRP-1400 N1	4
12	Ground Idle	2
Transition to Bio-fuel/JP-5 Blend		
13	Ground Idle	1
14	IRP	5
15	Max A/B	1
16	IRP-200 N1	4
17	IRP-400 N1	4
18	IRP-600 N1	4
19	IRP-800 N1	4
20	IRP-1000 N1	4
21	IRP-1200 N1	4
22	IRP-1400 N1	4
23	Ground Idle	2
24	Shut Down	

DISCUSSION

4. Prior to test initiation, the specific gravity of the standard JP-5 fuel measured 0.804 at 58°F and the JP-5/Bio-fuel blend measured 0.788 at 59°F. It was noted that the measured specific gravity for the JP-5/Bio-fuel blend was equal to the specified minimum allowable specific gravity for JP-5 fuel.

5. The lower heating value (LHV) of the JP-5 fuel measured 18,535 BTU/lb and the JP-5/Bio-fuel blend measured 18,745 BTU/lb. The minimum specification limit of JP-5 is 18,315 BTU/lb. These measurements were performed at the Propulsion System Evaluation Facility's Chemistry Laboratory at NAS Patuxent River.

6. Due to time constraints, the test was run at a relative humidity of 83%, which is higher than the recommended limit of 75% for engine performance verification testing.

F404 BIO-FUEL AND JP-5 PERFORMANCE RUNS

7. The following critical engine parameters were collected and monitored during the performance tests for both fuels:

a. Hush House Ambient Air Pressure (P_{cell})
b. Power Level Angle (PLA)
c. Fan Speed (N1)
d. Compressor Speed (N2)
e. Fuel Flow (WF)
f. Bellmouth Screen Temperatures (T_{screen})
g. Engine Inlet Temperatures (T1 EIP)
h. Compressor Discharge Pressure (CDP)
i. Exhaust Gas Pressure (PT5.6)
j. Turbine Exit Temperature Harness Average (T5HA)
k. Fan Variable Geometry Position (FVG)
l. Compressor Variable Geometry Position (CVG)
m. Variable Nozzle Area (A8)
n. Thrust (FN)

8. The steady state data were corrected to standard day conditions using classical delta and theta corrections. These corrections are based on T_{screen} and P_{cell} measurements and are used for the performance analysis. Measured fuel flow was also corrected for specific gravity and LHV. The following relationships were analyzed to compare engine performance:

a. N2C versus N1C
b. FVG versus N1C
c. CVG versus N2C
d. EPR versus N1C
e. CDPC versus N2C
f. T5HAC versus N1C
g. WFC versus N2C
h. FN versus N1C
i. FN versus WFC
j. FN versus T5HAC
k. A8 versus PLA

9. In general, there was no significant difference between the JP-5 data and the JP-5/Bio-fuel data. The engine performance deltas for the JP-5/Bio-fuel blend were plotted against the acceptable instrumentation uncertainty ranges. This range is defined as ±1% deviation from the JP-5 fuel data for all measures of speed, temperature, pressure, fuel flow and thrust. The acceptable uncertainty range for measured guide vane angles is defined as ±3 deg.

All of the JP-5/Bio-fuel deltas values fell within these limits of uncertainty with the exception of one test point. Test point No. 17 (IRP-400 N1) produced EPR and FN delta values beyond the acceptable measurement uncertainty limits when plotted against N1C. This has been determined to be a result of a decrease in A8; however, this oscillation was a function of the engine controls system and is unrelated to the introduction of JP-5/Bio-Fuel to the engine. Limited JP-5/Bio-Fuel quantities prevented additional testing to further investigate this anomaly.

The measured deltas and corresponding uncertainty ranges for the analyzed performance relationships are illustrated in the appendix.

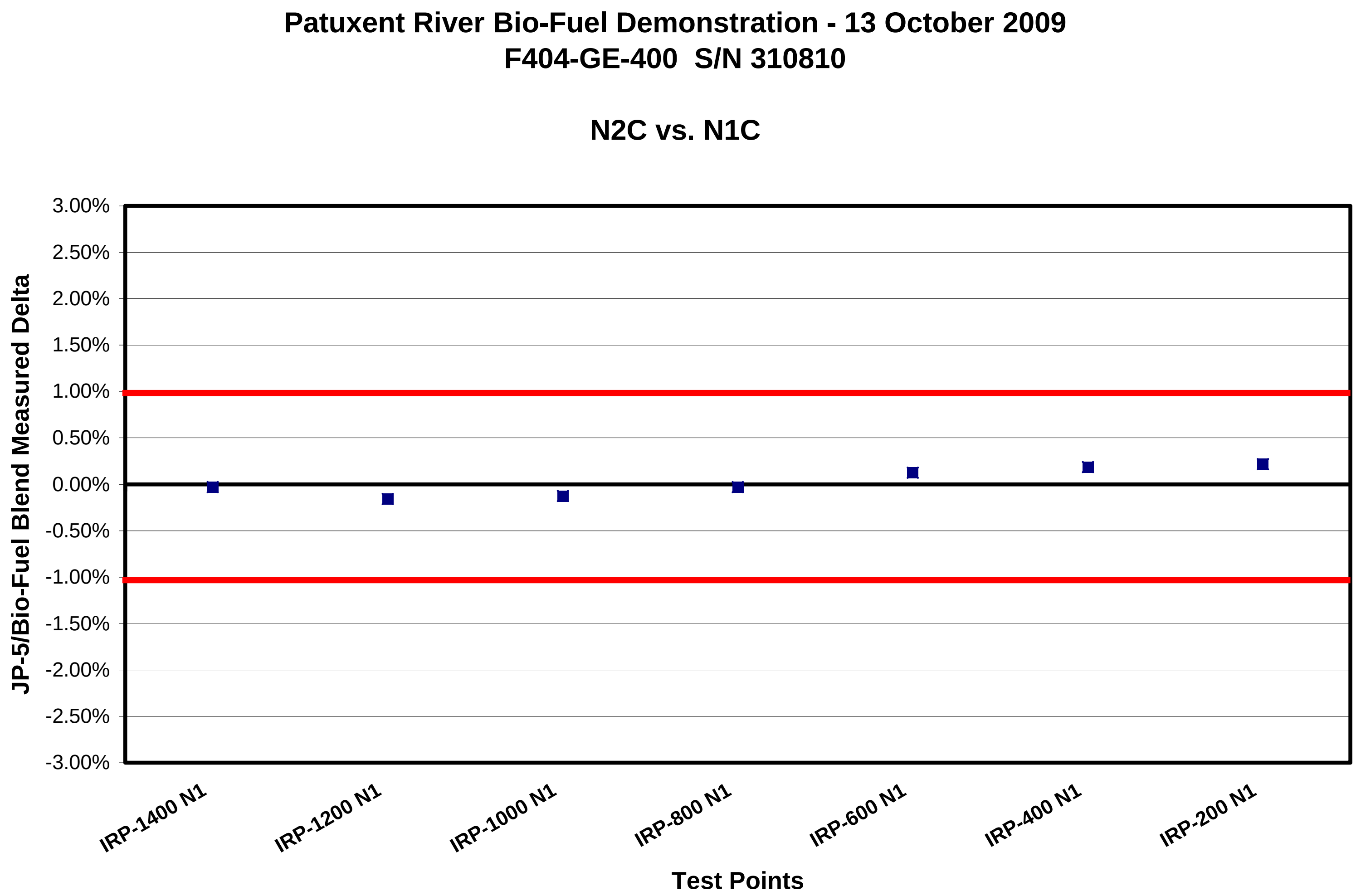
CONCLUSION

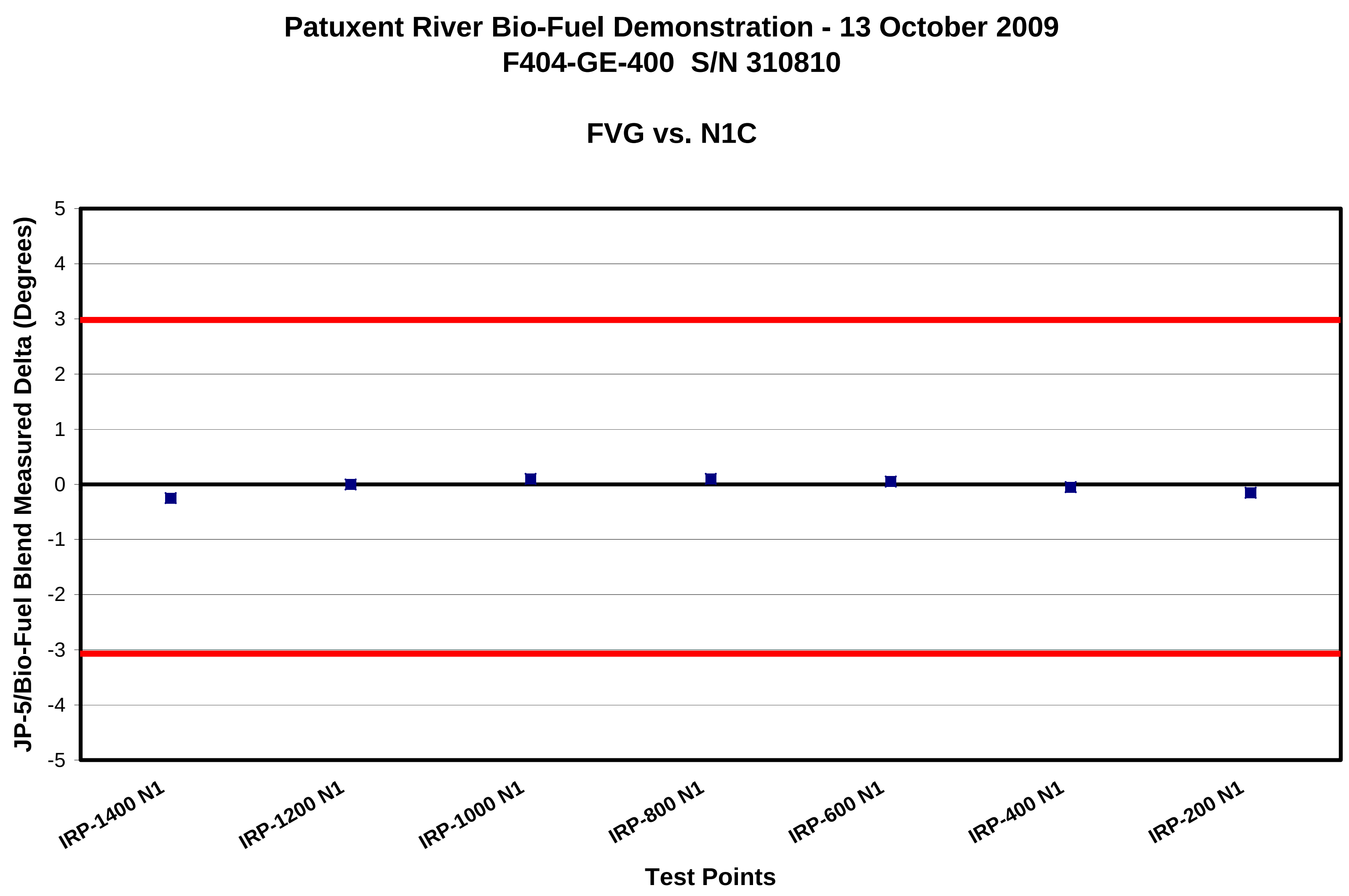
10. Based on the overall results of this test, F404-GE-400 engine performance throughout the complete power operating range was not changed while operating on the JP-5/Bio-fuel blend compared to the standard JP-5 fuel.

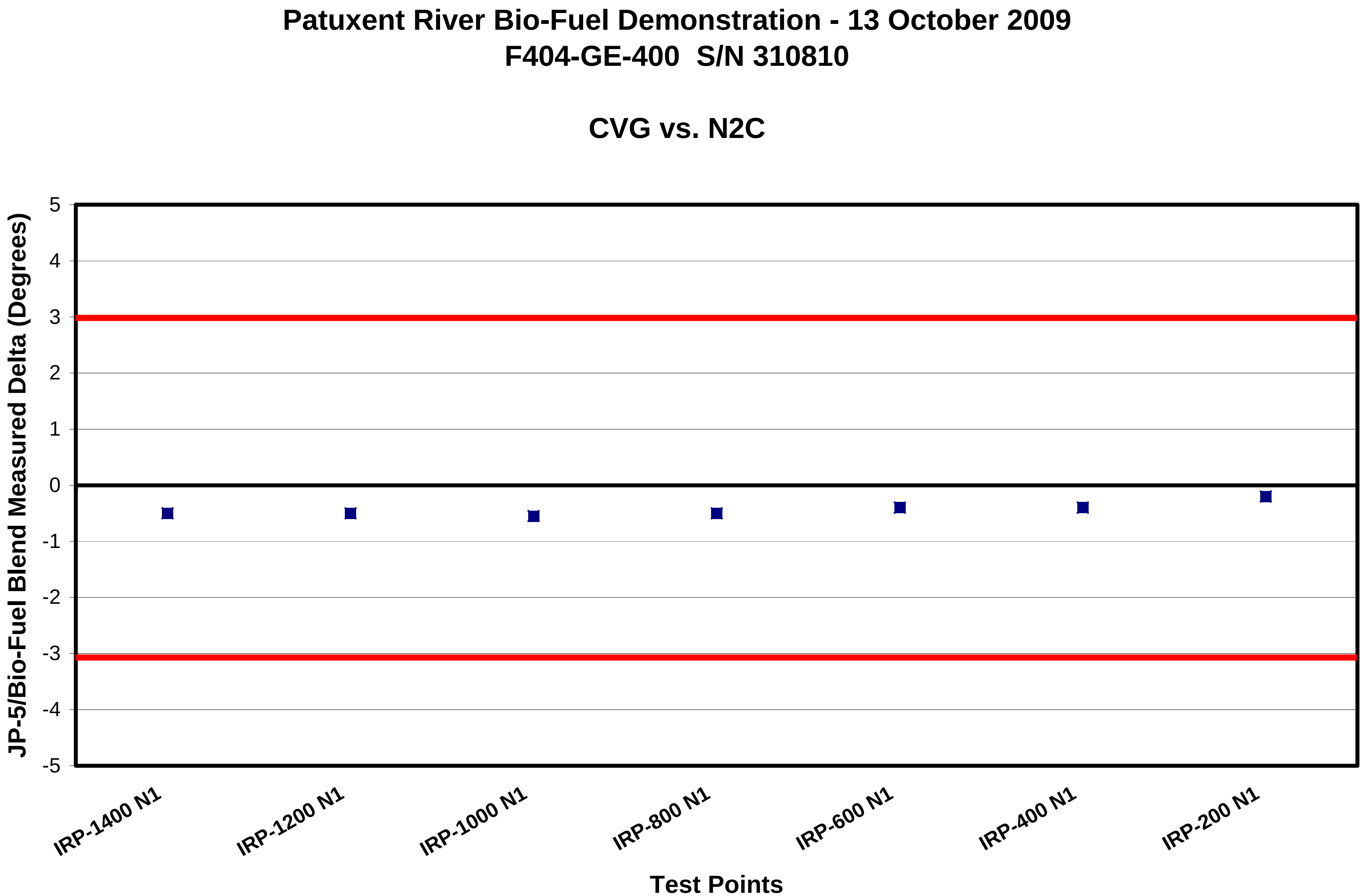
POINT OF CONTACT

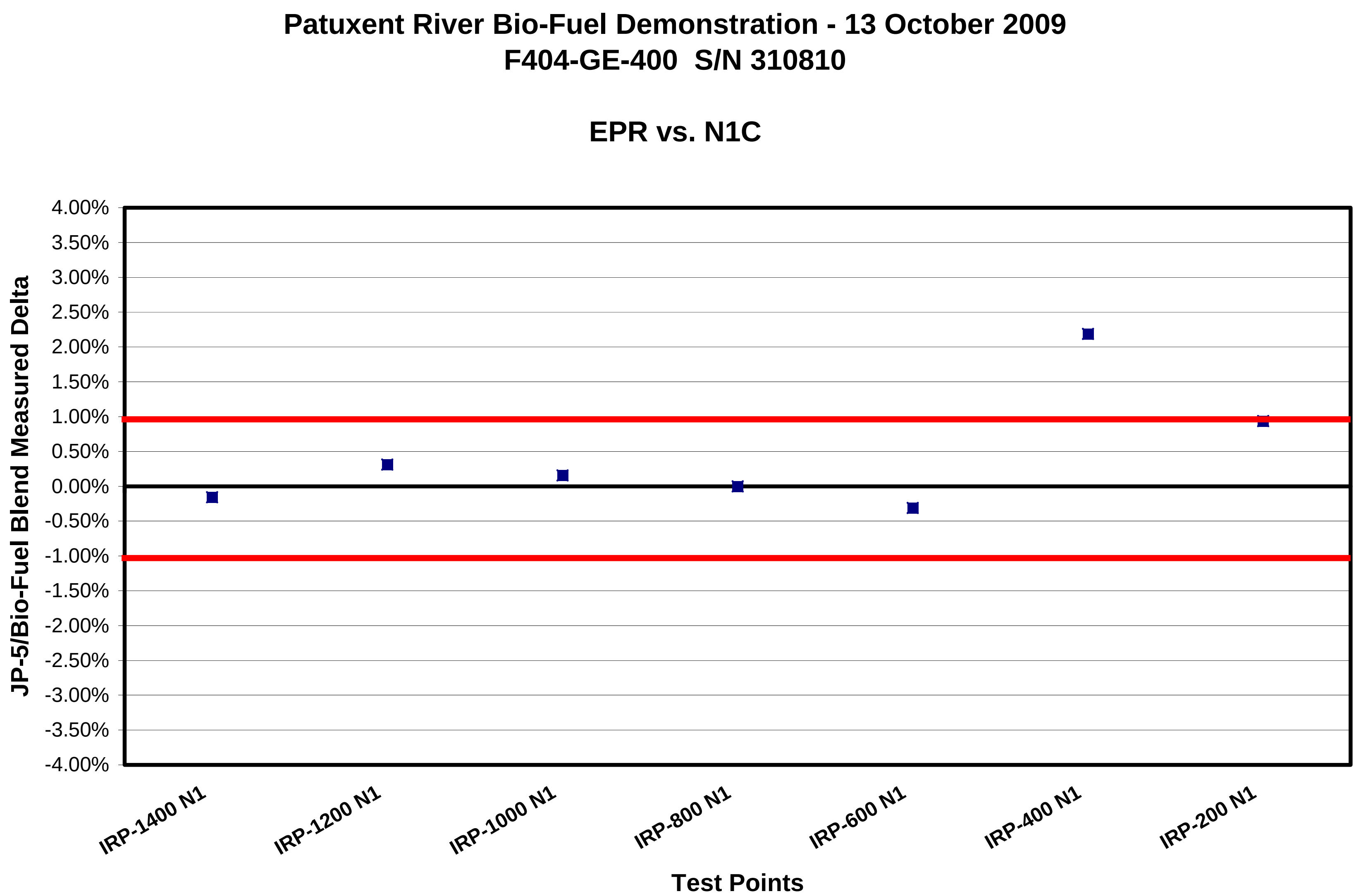
11. Any questions or comments regarding this test can be directed to Christopher Chippa, Propulsion and Power Engineering, AIR-4.4.6.4, Patuxent River, Maryland. Commercial phone is 301-757-0427 or DSN 757-0387.

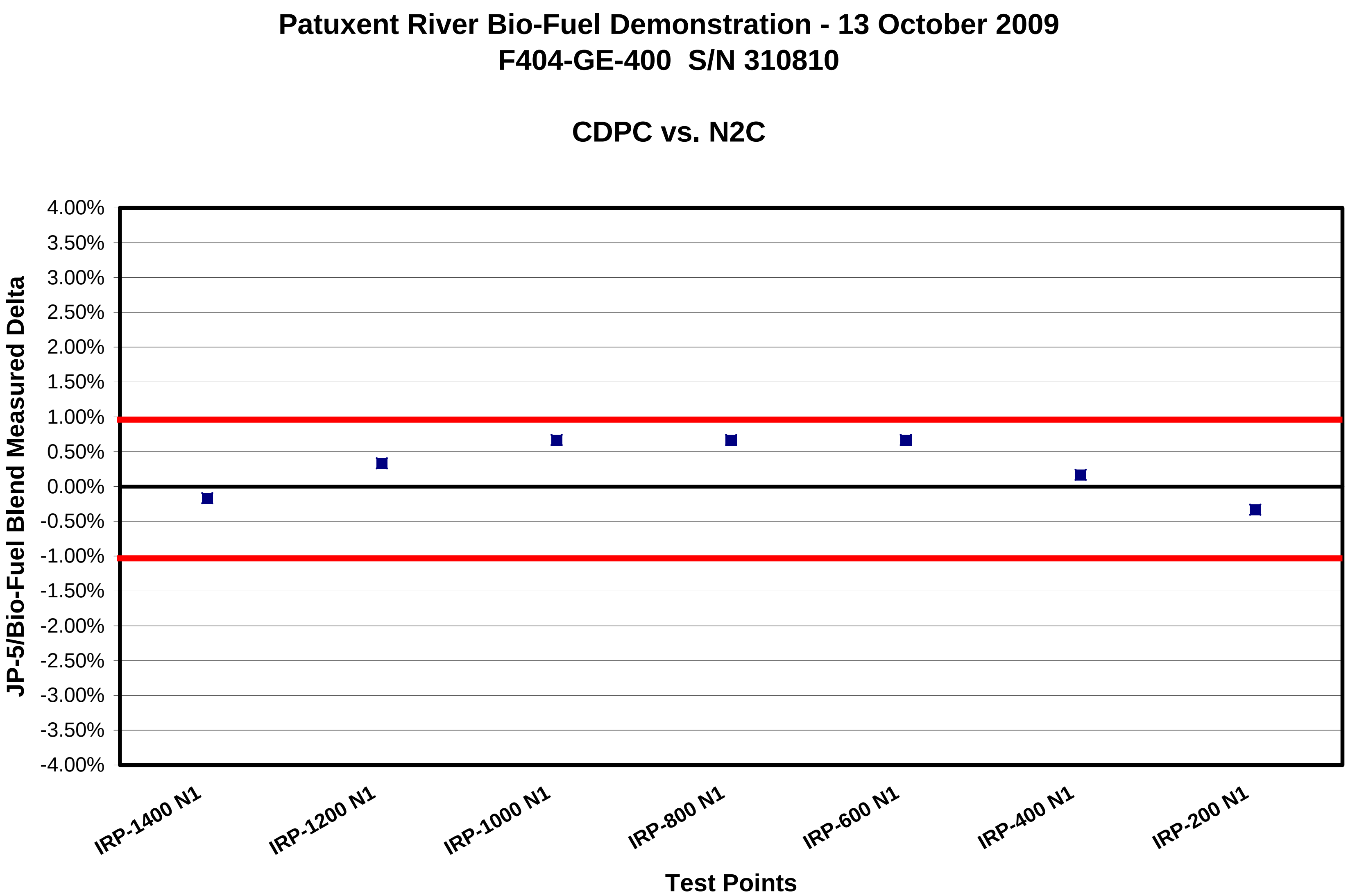
APPENDIX
BIO-FUEL DEMONSTRATION

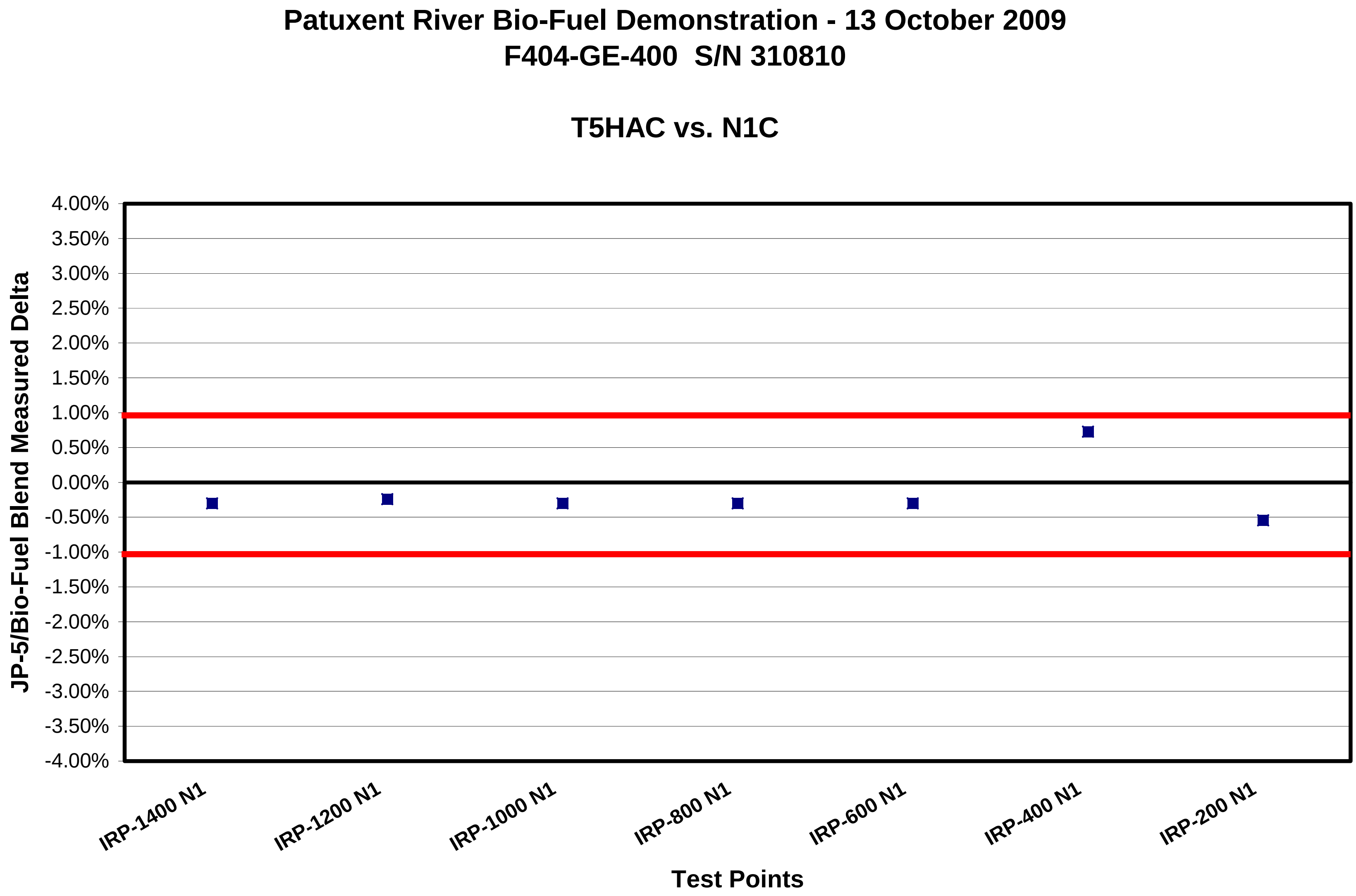


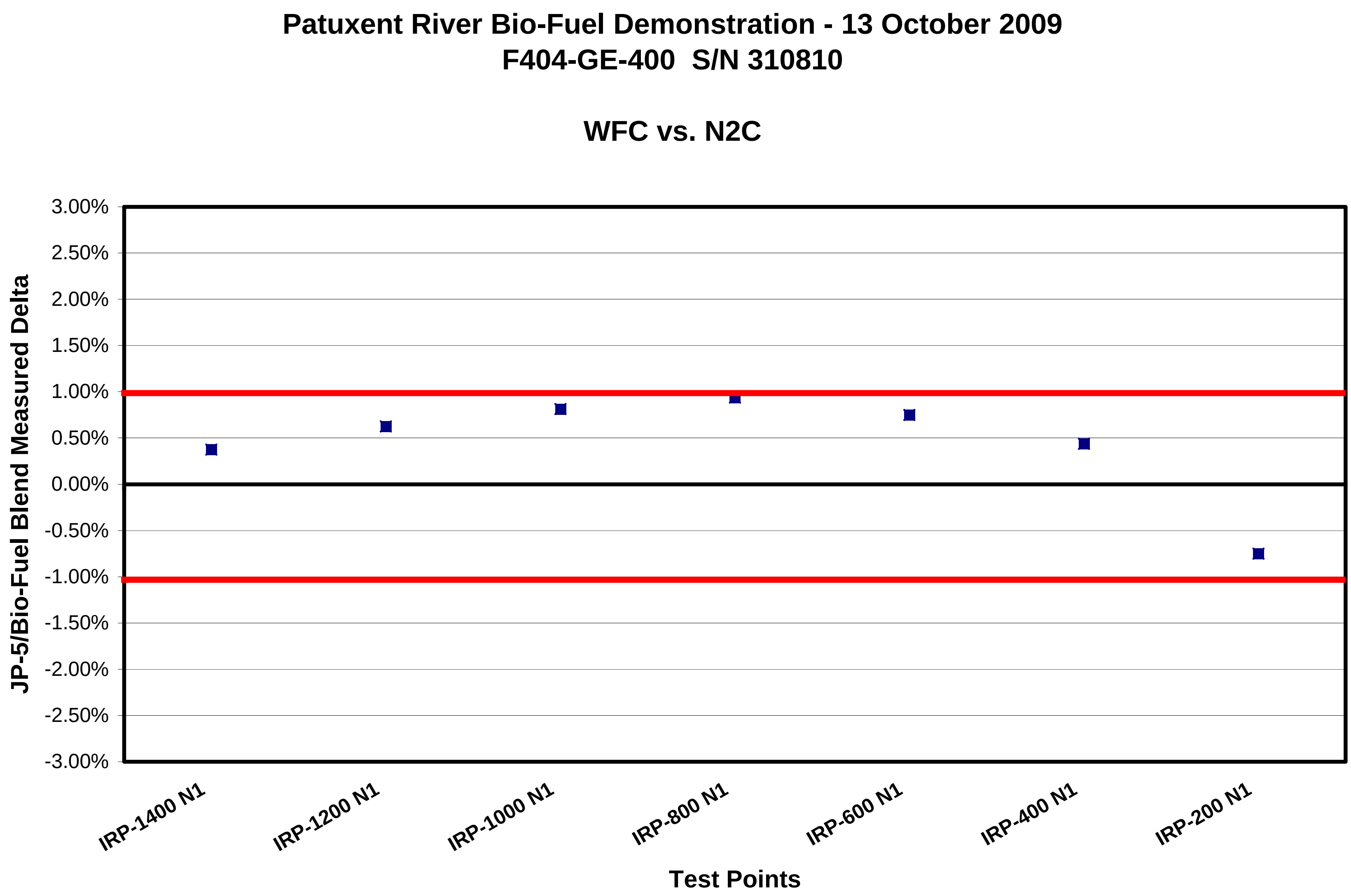

Patuxent River Bio-Fuel Demonstration - 13 October 2009
F404-GE-400 S/N 310810
FVG vs. N1C
JP-5/Bio-Fuel Blend Measured Delta (Degrees)
5
4
3
2
1
0
-1
-2
-3
-4
-5
IRP-1400 N1
IRP-1200 N1
IRP-1000 N1
IRP-800 N1
IRP-600 N1
IRP-400 N1
IRP-200 N1
Test Points

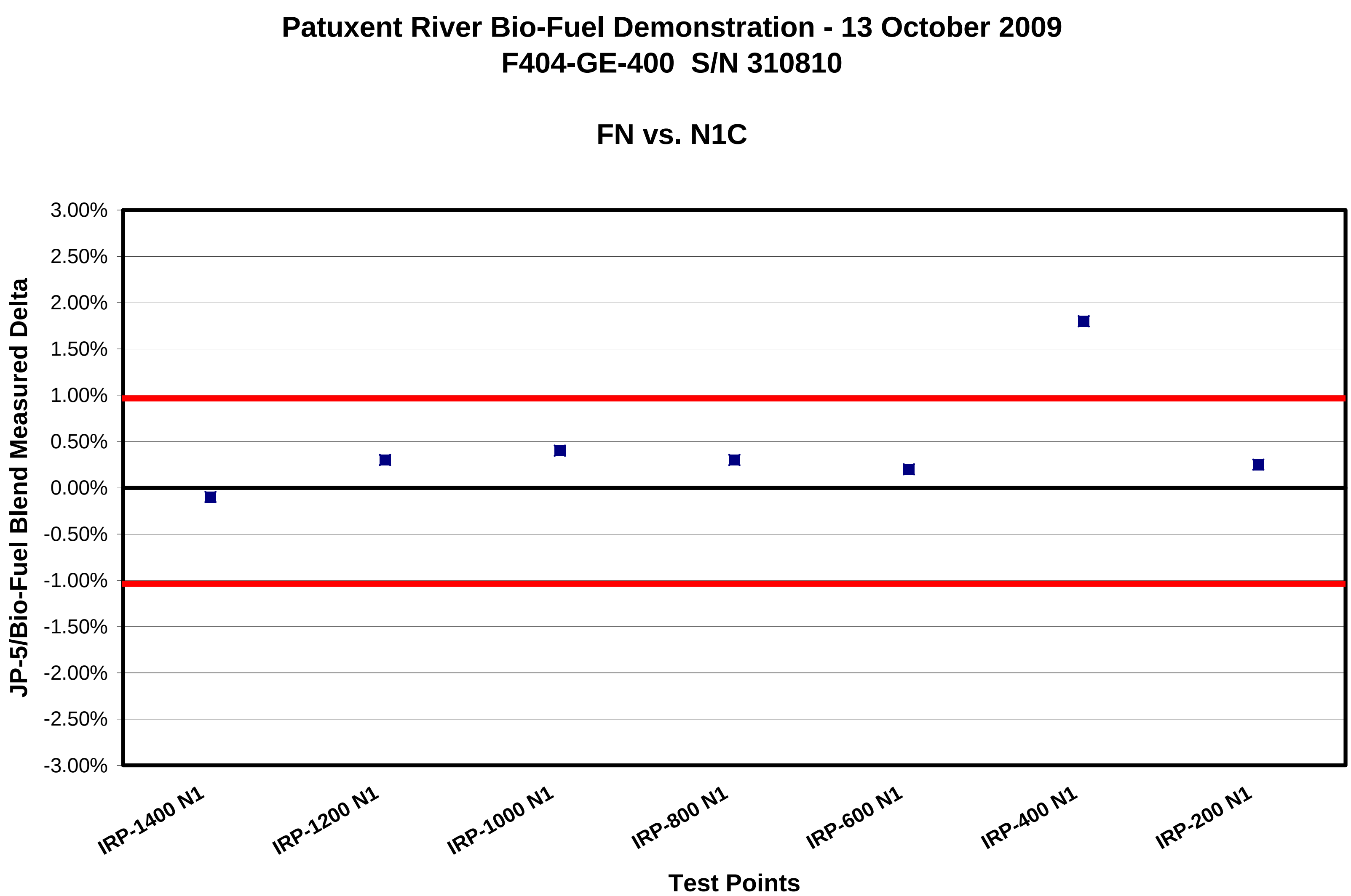

Patuxent River Bio-Fuel Demonstration - 13 October 2009
F404-GE-400 S/N 310810
CVG vs. N2C
JP-5/Bio-Fuel Blend Measured Delta (Degrees)
5
4
3
2
1
0
-1
-2
-3
-4
-5
IRP-1400 N1
IRP-1200 N1
IRP-1000 N1
IRP-800 N1
IRP-600 N1
IRP-400 N1
IRP-200 N1
Test Points

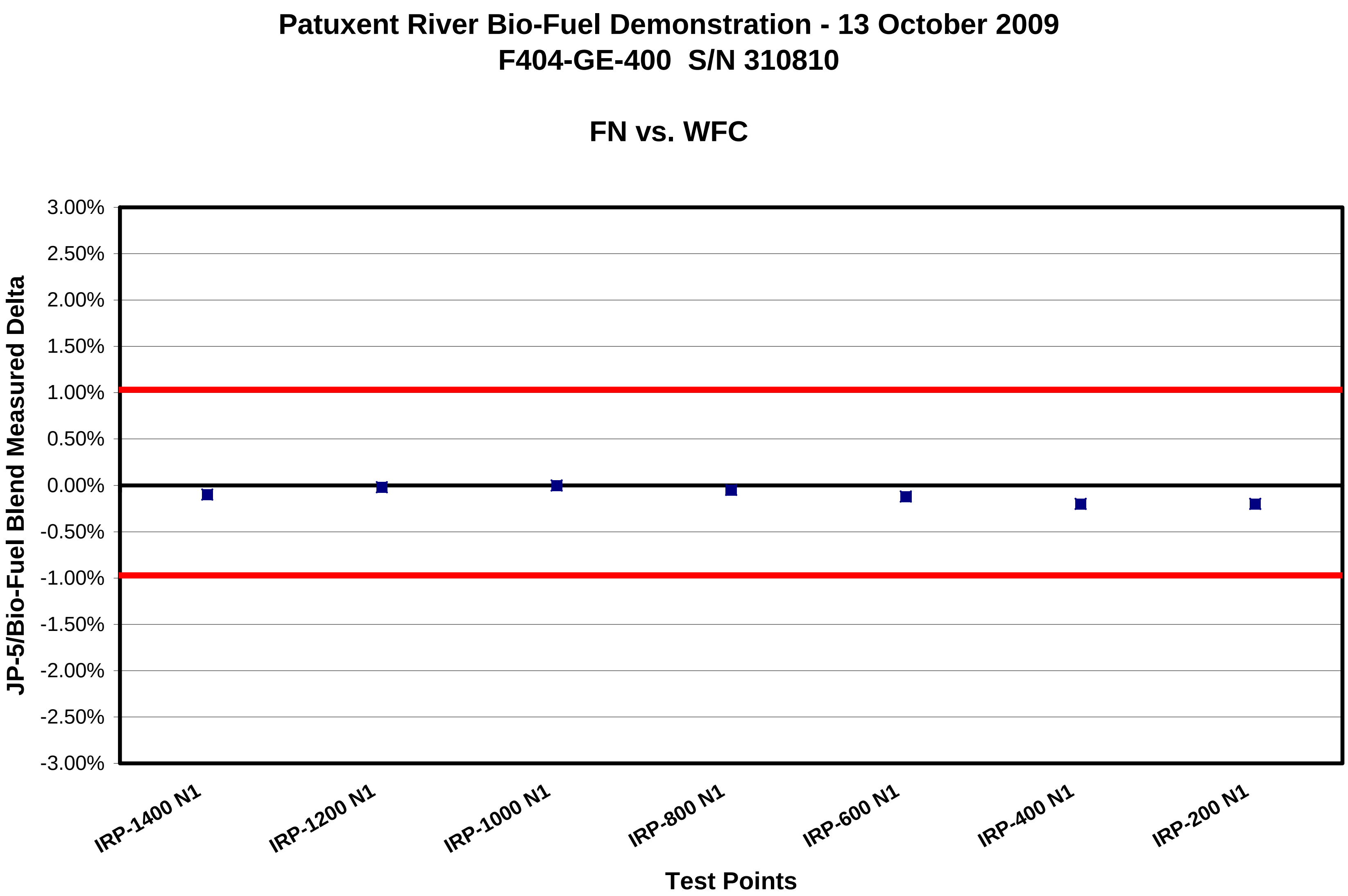

Patuxent River Bio-Fuel Demonstration - 13 October 2009
F404-GE-400 S/N 310810
EPR vs. N1C
JP-5/Bio-Fuel Blend Measured Delta
4.00%
3.50%
3.00%
2.50%
2.00%
1.50%
1.00%
0.50%
0.00%
-0.50%
-1.00%
-1.50%
-2.00%
-2.50%
-3.00%
-3.50%
-4.00%
IRP-1400 N1
IRP-1200 N1
IRP-1000 N1
IRP-800 N1
IRP-600 N1
IRP-400 N1
IRP-200 N1
Test Points

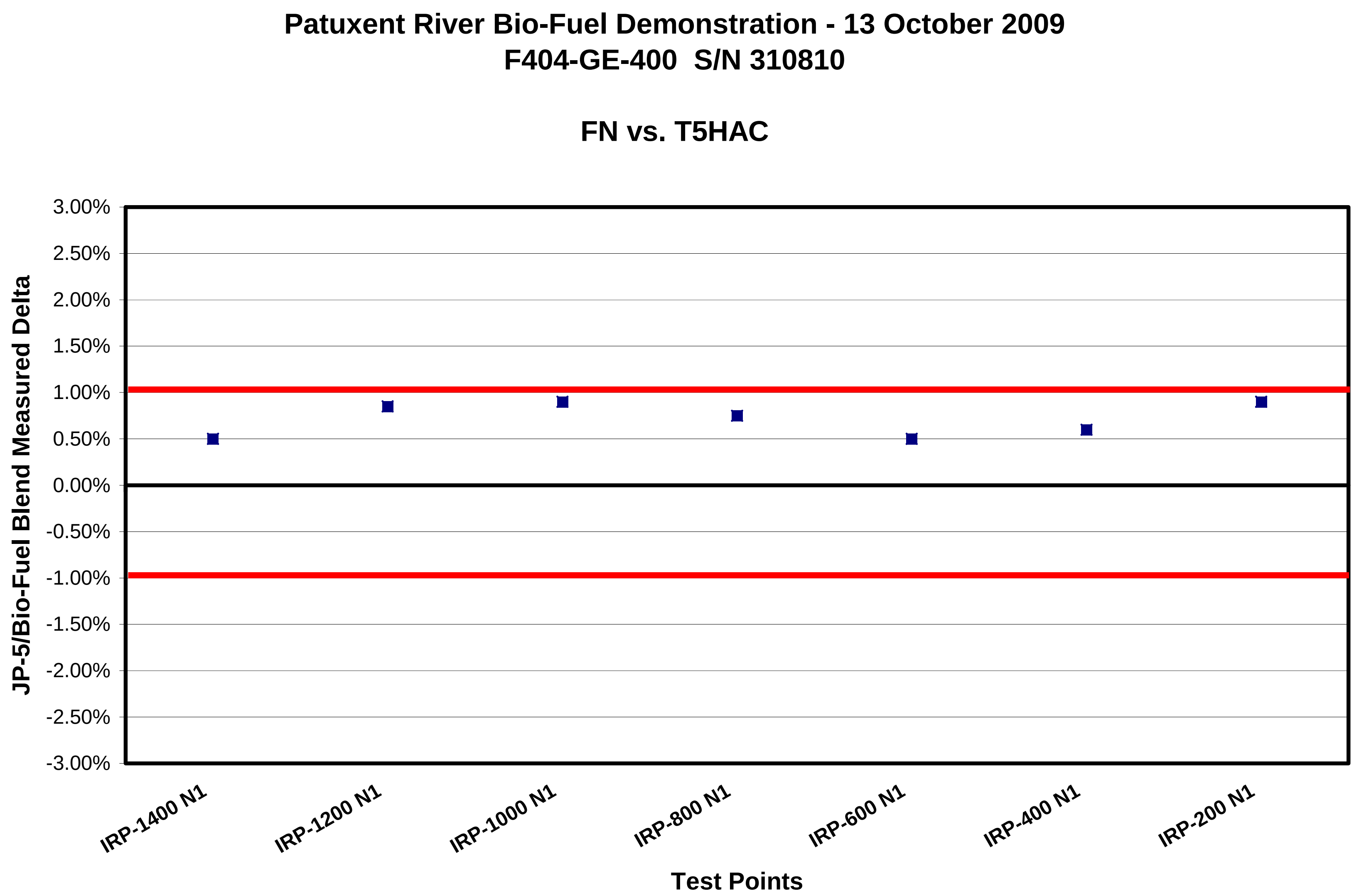

Patuxent River Bio-Fuel Demonstration - 13 October 2009
F404-GE-400 S/N 310810
CDPC vs. N2C
4.00%
3.50%
3.00%
2.50%
2.00%
1.50%
1.00%
0.50%
0.00%
-0.50%
-1.00%
-1.50%
-2.00%
-2.50%
-3.00%
-3.50%
-4.00%
JP-5/Bio-Fuel Blend Measured Delta
IRP-1400 N1
IRP-1200 N1
IRP-1000 N1
IRP-800 N1
IRP-600 N1
IRP-400 N1
IRP-200 N1
Test Points

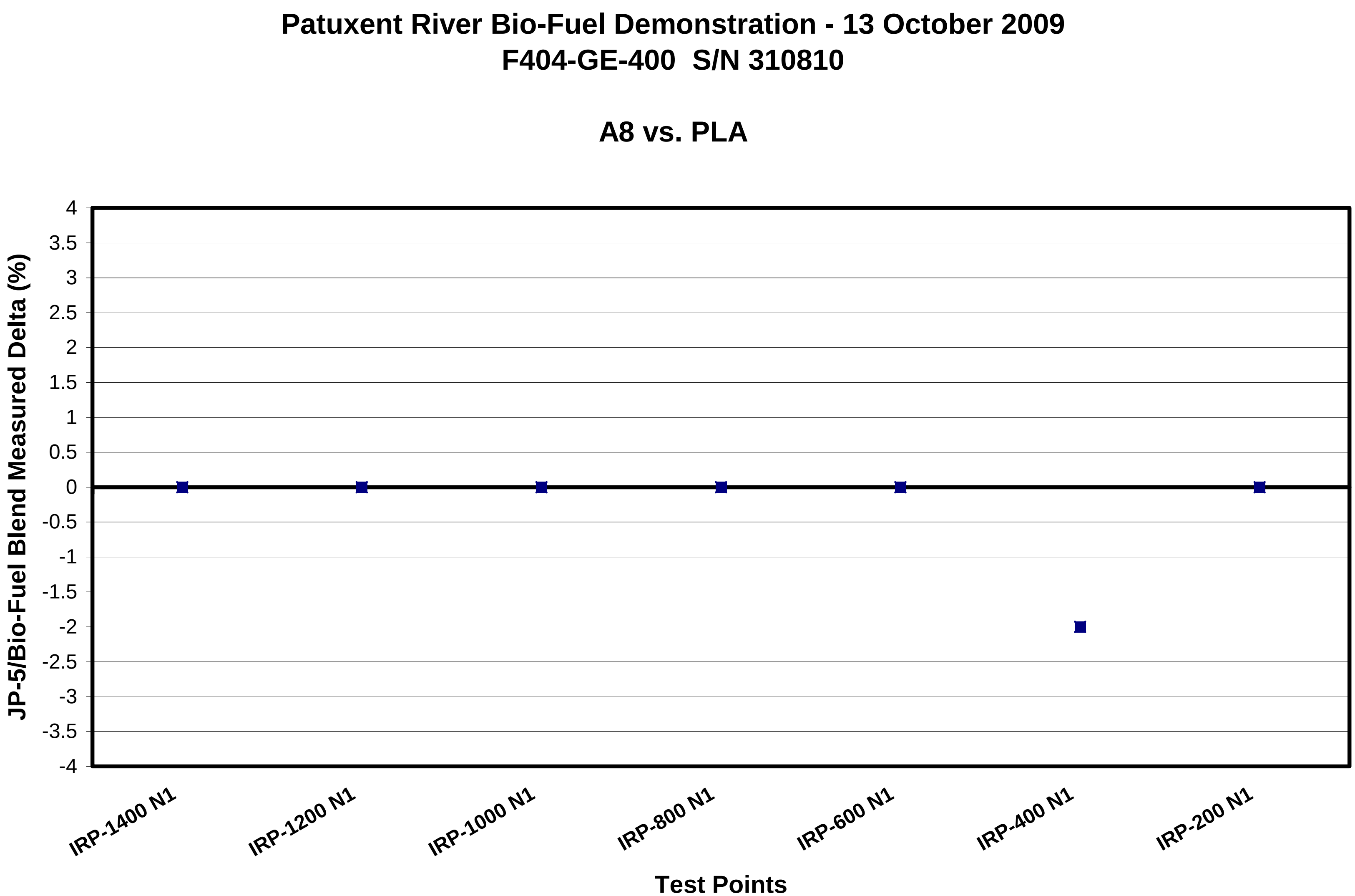

Patuxent River Bio-Fuel Demonstration - 13 October 2009
F404-GE-400 S/N 310810
T5HAC vs. N1C
JP-5/Bio-Fuel Blend Measured Delta
4.00%
3.50%
3.00%
2.50%
2.00%
1.50%
1.00%
0.50%
0.00%
-0.50%
-1.00%
-1.50%
-2.00%
-2.50%
-3.00%
-3.50%
-4.00%
IRP-1400 N1
IRP-1200 N1
IRP-1000 N1
IRP-800 N1
IRP-600 N1
IRP-400 N1
IRP-200 N1
Test Points


Patuxent River Bio-Fuel Demonstration - 13 October 2009
F404-GE-400 S/N 310810
WFC vs. N2C
JP-5/Bio-Fuel Blend Measured Delta
3.00%
2.50%
2.00%
1.50%
1.00%
0.50%
0.00%
-0.50%
-1.00%
-1.50%
-2.00%
-2.50%
-3.00%
IRP-1400 N1
IRP-1200 N1
IRP-1000 N1
IRP-800 N1
IRP-600 N1
IRP-400 N1
IRP-200 N1
Test Points


Patuxent River Bio-Fuel Demonstration - 13 October 2009
F404-GE-400 S/N 310810
FN vs. N1C
JP-5/Bio-Fuel Blend Measured Delta
3.00%
2.50%
2.00%
1.50%
1.00%
0.50%
0.00%
-0.50%
-1.00%
-1.50%
-2.00%
-2.50%
-3.00%
IRP-1400 N1
IRP-1200 N1
IRP-1000 N1
IRP-800 N1
IRP-600 N1
IRP-400 N1
IRP-200 N1
Test Points


Patuxent River Bio-Fuel Demonstration - 13 October 2009
F404-GE-400 S/N 310810
FN vs. WFC
JP-5/Bio-Fuel Blend Measured Delta
3.00%
2.50%
2.00%
1.50%
1.00%
0.50%
0.00%
-0.50%
-1.00%
-1.50%
-2.00%
-2.50%
-3.00%
IRP-1400 N1
IRP-1200 N1
IRP-1000 N1
IRP-800 N1
IRP-600 N1
IRP-400 N1
IRP-200 N1
Test Points


Patuxent River Bio-Fuel Demonstration - 13 October 2009
F404-GE-400 S/N 310810
FN vs. T5HAC
JP-5/Bio-Fuel Blend Measured Delta
3.00%
2.50%
2.00%
1.50%
1.00%
0.50%
0.00%
-0.50%
-1.00%
-1.50%
-2.00%
-2.50%
-3.00%
IRP-1400 N1
IRP-1200 N1
IRP-1000 N1
IRP-800 N1
IRP-600 N1
IRP-400 N1
IRP-200 N1
Test Points


Patuxent River Bio-Fuel Demonstration - 13 October 2009
F404-GE-400 S/N 310810
A8 vs. PLA
JP-5/Bio-Fuel Blend Measured Delta (%)
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
IRP-1400 N1
IRP-1200 N1
IRP-1000 N1
IRP-800 N1
IRP-600 N1
IRP-400 N1
IRP-200 N1
Test Points

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